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THE EVOLUTION OF METHODS OF AIR TRAFFIC CONTROL(U)  
ROYAL SIGNALS AND RADAR ESTABLISHMENT MALVERN (ENGLAND)  
P T HUMPHREY 1984 RSRE-MEMO-3724 DRIC-BR-93761

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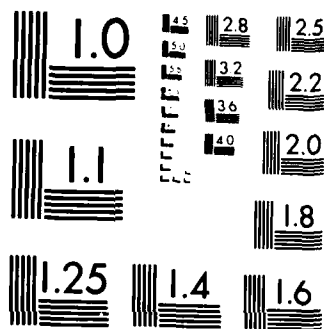
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THE EVOLUTION OF METHODS OF AIR TRAFFIC CONTROL

Author: P T Humphrey

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## ROYAL SIGNALS AND RADAR ESTABLISHMENT

Memorandum 3724

Title: THE EVOLUTION OF METHODS OF AIR TRAFFIC CONTROL

Author: P T Humphrey

Date: July 1984

## SUMMARY

This Memo proposes a means whereby ATC method could evolve to take advantage of developments in civil airline avionics and the opportunity of an ATC air-ground data link.

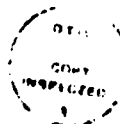
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THE EVOLUTION OF METHODS OF AIR TRAFFIC CONTROL

P T Humphrey

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## 1 INTRODUCTION

After a period of development of the ATC system during which the ATC methods have been able to adapt quite smoothly, there is in prospect more radical change. The possibilities of new communication technology and of computer assistance for the controller make a reconsideration of the ATC methods themselves necessary. In order for the evolution of the technology as applied to ATC to be planned, the philosophy of ATC must also be planned to evolve in harmony.

This evolution in the ATC system must cope with a customer who will gradually move from one generation of aircraft to the next, with the controller and pilot who will have to change their practice through training and lastly with the ATC authorities who will progressively re-equip with the new technology as their budgets allow.

The fact that changes will occur is not open to doubt. Already many airlines have refitted older aircraft with new avionics in order to reduce operating costs and new aircraft are being fitted as standard with advanced navigation and flight management equipment. The pressure to be able to use this new avionic equipment as fully as possible is mounting but such plans need to be assessed in the context of how the total ATC system could evolve, both ground and air. Such equipment should operate with advantage not just with the present ATC system but with the likely developments in ATC such as the use of computer assisted sequencing by speed control. Likewise, new ATC methods need to be considered which could utilise the new avionics capabilities.

There has been some assessment at RSRE of how this evolution in ATC methods could happen and this paper describes the first suggestion.

## 2 CURRENT ATC PHILOSOPHY

In order to understand the changes which may be considered the following characteristics of the current ATC system should be appreciated.

### (a) Method of Control

When an aircraft enters an area of controlled airspace, the pilot calls on the RT the relevant ATC control centre and thereafter will obey the instructions given by that centre. These commands are given with no strategy necessarily obvious to the aircrew and with a set of objectives which apply to the whole ATC system and not to individual aircraft, namely, safety, orderliness and expedition. This last factor, expedition includes a general idea of economy for the airline but there is no means available to the controller to apply it in any detailed way.

### (b) Iterative Control

As has been suggested earlier, the method of control by the ATCO has only a very broad strategy and the commands are only given to the aircraft one by one. This iterative approach is determined by the inability of the controller to predict very far ahead because he only has the radar screen to assist him. He tries to keep his options open until he has to act and so he would have a major bias against a new system which forced him to make long term detailed plans and to communicate them to the aircraft well in advance.

(c) Control Variables

The aircraft state variables which can be controlled by the ATCO are the plan position, the height and the speed. Considering each in turn.

Plan position:

The ground measurement of position is by radar and it is used to check that the aircraft are keeping to their routes and that there is no possibility of the separation standards being infringed. The routes are defined by beacons which the aircraft generally will have to overfly and so except in one particular area the radar positional information is normally not used for lateral navigation. The one major exception to this is in the airspace between the stack and the runway where the Radar Director will form the landing stream by giving heading commands in order to get the correct spacing. Note however that the aircraft will all have a standard speed by that time.

Height:

The height measurement of each aircraft is obtained, not from radar directly, but from the report of pressure altitude from the aircraft altimeter in the Mode-C SSR reply. It is presented to the ATCO as part of a label on the radar display. For the reason that the altimeter has been, up until recently, the most accurate aircraft positional measurement and that it reduces the ATC task to a mostly one-dimensional problem which the ATCO can tackle, height is the variable which is often used to achieve tactical control of aircraft. As an example, two aircraft, one climbing and one descending, are on intersecting routes and it is predicted that they will conflict if they continue on their current flight plans. The ATCO need not alter their speeds or take them off their routes or change their climb/descent rates, any of which might solve the conflict, but he tells the descender to level out at 15000 ft and the ascender to level out at 14000 ft (for a conflict which could have occurred at 15000ft). He has thereby avoided any possibility of a conflict without needing any detailed knowledge of speed or time and it is a fail-safe procedure which leaves the ATCO time to choose his next move.

Speed:

The aircraft speed is not measured independently on the ground in the UK for presentation to the ATCO. All he has is the flight plan speed or the last clearance given and hence, it is not used for as a control variable but only for 'rule of thumb' separation.

(d) ATC System Capacity

The capacity of the present ATC system (ie movements per hour) is limited at present in two areas. Firstly there is a runway capacity limit at major airports at peak times. For example, at London Heathrow the runways are operating at peak rates for most of the daytime for most of the year and 'whole-plane' charter traffic is prohibited. At

peak arrival rates at Heathrow, aircraft are arriving at the rate of one every 90 seconds, which is difficult to improve on. The second capacity limit is at particular points in the route structure such as where routes cross and it is determined by airspace limits and by controller workload. It is, for instance, predicted that the present London TMA route structure will reach its capacity limits more generally within this decade even with the present forecast of only limited traffic growth and a new structure will have to be devised.

#### (e) Aircraft Fit

The basic design assumption of the current ATC practice is that, because of its historical development, it is designed around what are now the least equipped aircraft. Those aircraft with the advanced avionics fit have to make do. Examples of the great strides made in avionics, even for the simpler GA aircraft, are the scanning DME RNAV systems and the Performance Management/Flight Management computers. These would permit an ATC route to be defined without overflying of beacons and allow the fuel optimal descent parameters to be calculated.

### 3 THE DATA LINK ERA OF ATC

The conditions which will exist when an ATC data link is to be introduced will by then have changed markedly from today. By that time, it is anticipated, a major step forward in ATC system efficiency will have already taken place with the introduction of a computer aid for the controller. This will enable him to use speed control to sequence and meter traffic and so avoid stacking on most occasions and to give continuous descents.

The introduction of an ATC data link between individual aircraft and the ground ATC system will make it possible to send messages in each direction, both data and ATC instructions. With the considerable computing power which could be provided in the aircraft as well as on the ground, the question arises about how to divide the work between the air and the ground. If it is the information available which determines where decisions are made, how should the ATC decision making organisation be designed? If all the data necessary for a decision can be transferred, where is that decision best made? Or does it matter?

### 4 ATC BY OBJECTIVES

A new method of ATC, termed ATC By Objectives, attempts to overcome the deficiencies of the present practice which will be unacceptable in the 1990's and to show how the flexibility introduced by an ATC data link can be harnessed to produce a coherent ATC philosophy for the next century. To illustrate the factors involved, a basic method is described and then an improvement upon it.

In Fig 1 is listed the sequence of events which would take place upon entry to the FIR or upon transfer of control.

#### Data Exchange:

On transfer of control there would be an exchange of data between the aircraft and the ground system. The aircraft would tell of its avionics fit, its height and speed and would begin a regular report of



wind and temperature conditions and of its manoeuvre state (such as bank angle). From the ground would be passed the forecast met conditions at heights of interest along the route.

#### ATC Constraints:

The fundamental presupposition of this method is that it is only the aircraft which can make the choice of the most cost-efficient profile. Consequently the aircraft needs to be informed of the external ATC system constraints along that route, in particular, the slot times and available flight levels at congestion points along the route, including the runway/bottom of descent.

#### Choice of Profile:

From all the information given to it and what it knows of its own performance and priorities (for instance, time against fuel) the aircraft system chooses, what is by its own criteria, the best flight profile.

#### ATC Approval:

Whatever profile is chosen, the ground ATC system must have the final approval since it alone knows the full system situation and remains in legal responsibility in controlled air space. To do this it must, of course, repeat the calculations done by the aircraft, from the same data. If for some reason the aircraft choice is not acceptable then the process must be repeated.

#### Monitoring:

In order to discharge its responsibility, the ATC system would monitor the progress of the aircraft along its approved profile, and would seek correction of any significant deviation.

This process of control may be assessed by criteria listed in Fig 2. Considering each in turn.

#### Data Link Capacity:

The capacity of the Mode-S data link (as a contender for the ATC data link) would seem to be capable of handling the data required to be transferred. The limits may be more due to the geographical location of the Mode-S stations which would govern the peak capacity rather than message rate.

#### Traffic Loading:

All the data has to be exchanged no matter what the traffic conditions. At peak times there will be no choice of profile, it will be a matter of taking the only available slot in the stream.

#### Ground System Workload:

As has been described above, ATC would still have the responsibility to approve profiles and to monitor them and consequently would have to repeat calculations done in the aircraft. To do this all the data used

in the aircraft would be needed on the ground. Further, the calculations would have to be done and the profile chosen for those aircraft unable to do it for themselves. In all, the ATC system workload has increased since the work done previously on the ground remains, and in addition extra information has to be sent to each aircraft together with an extra stage in the control process.

#### Economics:

The assumption in this method is that the aircraft is in the best position to make the choice of the most economic profile. However this is not necessarily so. Even the comparatively simple aircraft representations available today, (such as those derived by Benoit and others at Euro-control) are capable of modelling aircraft performance quite accurately. It remains to be shown that even if this is significantly poorer than the aircraft's model of itself, the ground model could not be improved still further. Also with a data link some measure of an airline's economic priorities could be sent to the ground as a fuel/time cost ratio which would aid the profile optimisation at off-peak times.

#### Emergencies:

By agreeing to the entire profile very early, the controller is making it more difficult to cope with emergencies, for example, on the receiving runway. The ATCO would have to countermand all the previously approved profiles. The method generally goes against present philosophy by making commitments a long way before implementation and also before the controller could visualise the import of the commands given.

### 5 ATC BY OBJECTIVES - IMPROVED

Some of the disadvantages of the method of ATCBO as described arise because it does not reflect the natural roles of each component of the ATC system. The measures of effectiveness are economic and operational; and these must be evaluated for the whole ATC system. In economic terms, it is the customer airlines who pay ultimately through user charges and so there must be an overall benefit considering not only the direct operating costs but the return on investment in the ground equipment. Similarly in operational terms, improving the day-to-day quality of service for some aircraft could not be justified if it did not allow an acceptable overall service and a reasonable task for the controllers.

The contributions to system effectiveness are summarised in Fig 3. The fundamental functional breakdown is between planning and execution. The ground system collects and collates all the data of the whole of the traffic in Controlled Air Space, on the constraints which may exist (en-route, at the airports), on military activity and on emergencies. Whilst this role of the ground system remains largely unchanged from the past, the potential executive role of the aircraft has developed considerably. The accuracy of RNAV systems based on DME has improved enormously, and cheaply. The means for automatic closed loop control of flight paths will be available for the first time. It is these changes which offer the potential for improvements to ATC methods, not just the ability to have computers in aircraft.

The improvement to ATCBO, from the argument above, is to consider the ATC control loop between the pilot/FMS, and the ATCO/ATC-computer in two parts. The first is the outer slow loop in which the ground system will calculate and decide the objectives for each aircraft and then monitor progress. The second part of the control loop is the fast inner loop in which the FMS takes the objectives and sets out to achieve them. Assessing this modified method by the same criteria as before leads to the following conclusions.

#### Data Exchange:

The amount of data sent ground to air will reduce because only that which is necessary will be transmitted. This will be the next objective and the meteorological and other data necessary to achieve it. That sent air to ground will remain the same.

#### Traffic Loading:

The method now accommodates to the level of traffic and the consequent demand on ATC services. The profile is chosen on the ground and is the best possible in the circumstances. The constraints will vary according to traffic level and the ground system is able to decide whether they should be applied.

#### Ground System Work Load:

It is a working assumption that objectives will only be set when it is necessary for ATC purposes and any increase in ground system workload would therefore be for some benefit. As an example, if it were shown that capacity could be increased at a crossing point or junction, an objective could be set for it at busy periods. The entire mix of traffic can be accommodated.

#### Economics:

For the aircraft, the use of objectives together with monitoring would allow operation in the most efficient way. The ground ATC system retains the possibility of benefits resulting from using the new aircraft capabilities.

#### Emergencies:

The revised method allows ATC to revert to progressive control and so avoid unnecessary commitment too far in advance.

## 6 CONCLUSIONS

This improved method of ATC has the following characteristics which suggest it may be a viable long term prospect.

- (1) Each part of the 'ATC System' is performing the role that it can do best.

(2) The data link ensures that any future developments in ATC methods which can use greater prediction accuracy with the best equipped aircraft can be accommodated.

(3) The method is a descendent of present methods and can evolve as the need dictates. This is an important point because neither the ATC system nor the aircraft mix is going to change radically overnight. Any new system must be able to be introduced progressively so that the whole integrated ATC system may evolve and develop.

(4) There is the prospect that this evolution will increase capacity and efficiency and so bring benefit to the airlines who are the customers.

(5) Consideration has been given here to how aircraft with advanced avionics could operate within a busy ATC system, typically, Western Europe or N. America. By employing the aircraft capabilities in those situations, it increases the incentive to fit the equipment and make gains in other less constrained parts of the world.

# ATC BY OBJECTIVES

1. DATA EXCHANGE
2. AIRCRAFT TOLD OF CONSTRAINTS
3. AIRCRAFT MAKES CHOICE OF PROFILE
4. ATC CHECKS AND APPROVES/REJECTS
5. ATC MONITORS

FIG 1

### ASSESSMENT CRITERIA

1. DATA LINK CAPACITY
2. TRAFFIC LOADING
3. GROUND SYSTEM WORKLOAD
4. ECONOMICS
5. EMERGENCIES

FIG 2

CONTRIBUTIONS TO SYSTEM EFFECTIVENESS

Ground System: ATC PLANNING ROLE

Traffic Information  
System Constraints  
Met. Forecasts

AIRCRAFT: EXECUTIVE ROLE

Accurate Closed Loop Control  
Accurate Navigation

FIG 3

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